



ORIGINAL ARTICLE

Effect of Muay Thai training frequency on VO₂ max and muscle endurance in non-athletic adults: a randomized clinical trial

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ABSTRACT

BACKGROUND

Urban lifestyles have become increasingly sedentary, contributing to reduced physical fitness. Muay Thai, a high-intensity martial art, has been proposed as an effective exercise modality to improve aerobic capacity and muscle endurance. This study aimed to evaluate the effects of different weekly Muay Thai training frequencies on VO₂ max and muscle endurance in non-athletic adults.

METHODS

A randomized experimental study with a pre-test–post-test design was conducted involving 40 non-athletic adults (aged 20–25 years). Participants were randomly allocated into two groups: training twice weekly (MT2X) or four times weekly (MT4X) for eight weeks. Outcomes included VO₂ max and upper, abdominal, and lower body muscle endurance. Baseline characteristics were described descriptively. Between-group differences in post-intervention outcomes were analyzed using analysis of covariance (ANCOVA), with baseline values included as covariates.

RESULTS

At baseline, VO₂ max, abdominal, and lower body muscle endurance were higher in the MT4X group. After adjustment for baseline values using ANCOVA, the MT4X group demonstrated significantly higher post-intervention VO₂ max compared with the MT2X group (adjusted mean difference, $p < 0.001$). Significantly greater improvements favoring the MT4X group were also observed for upper body muscle endurance (push-ups, $p < 0.001$), abdominal muscle endurance (sit-ups, $p < 0.001$), and lower body muscle endurance (squats, $p = 0.018$).

CONCLUSION

A higher frequency Muay Thai training program is effective in significantly improving participants' aerobic capacity and muscle endurance. Practitioners are able to choose their training frequency preference, since both frequencies provide similar adaptation.

Keywords: Cardiovascular fitness, Muay Thai, muscle endurance, sedentary lifestyle, VO₂ max

INTRODUCTION

A sedentary lifestyle is a pattern in which a person, while awake, engages in minimal movement or physical activity and expends little energy in daily activities. This lifestyle has become widespread globally due to limited space available for exercise, increased sedentary behavior caused by occupations such as office work, and greater access to devices such as television and video games. Sedentary behavior has significant negative effects on the human body, including an increased mortality rate.⁽¹⁾

Lack of physical activity negatively affects aerobic capacity, muscle strength, and body flexibility. This condition increases the risk of chronic diseases such as obesity and other metabolic disorders. Research shows that regular physical activity can improve work capacity during strenuous physical tasks or reduce the relative workload when performing activities of a certain intensity.⁽²⁾ Additionally, urban environments that support mobility, such as adequate sidewalks, can encourage individuals to be more physically active and reduce sedentary behavior duration.⁽³⁾ The World Health Organization (WHO) recommends that adults aged 18–64 years engage in at least 150 minutes of moderate physical activity or 75 minutes of vigorous physical activity per week to maintain health.⁽⁴⁾

Several aspects relate to a person's health and physical fitness such as VO₂ max and muscle endurance. VO₂ max represents the maximal rate at which the body can consume oxygen during vigorous or exhaustive exercise, and is regarded as the gold standard index of cardiorespiratory fitness. Higher levels of VO₂ max reflect greater aerobic capacity and overall cardiovascular health. Numerous studies over recent years have demonstrated that individuals with higher VO₂ max values exhibit greater work capacity and a lower risk of cardiovascular disease and mortality compared with those who have low VO₂ max.⁽⁵⁾ Muscular endurance is the ability of muscles to

perform repeated contractions without fatigue. Good muscular endurance is essential for carrying out daily activities and contributes to a better quality of life. Exercises aimed at improving muscular endurance, such as resistance training, have been shown to effectively increase muscle strength and prevent muscle mass decline with aging.⁽⁶⁾

Muay Thai not only improves muscular strength but also enhances cardiovascular endurance and flexibility.⁽⁷⁾ Evidence from a recent study indicates that Muay Thai training can positively affect cardiovascular health by improving blood pressure and autonomic regulation, while also supporting better body composition and overall physical fitness.⁽⁸⁾ These findings suggest that regular participation in Muay Thai offers meaningful health benefits for adults seeking an efficient, full-body workout.⁽⁸⁾ Previous research has shown that Muay Thai training offers various fitness benefits, including increased muscle strength, cardiovascular endurance, coordination, and flexibility. For example, one study found that after eight weeks of Muay Thai training conducted three times per week, participants experienced significant improvements in muscle strength, cardiovascular endurance, agility, and Muay Thai skills ($p < 0.05$).⁽⁹⁾ Another study reported that a 24-week training program significantly enhanced coordination and lower limb performance compared to a bodybuilding regimen ($p = 0.011$ and $p = 0.038$).⁽¹⁰⁾

Rapkiewicz et al.⁽¹¹⁾ reported that 13 weeks of Muay Thai practice improved physical fitness in healthy untrained women, and that these benefits occurred regardless of whether training frequency was two or three times per week, suggesting that moderate weekly frequency already elicits meaningful adaptation in non athletes. Previous studies in combat sports and Muay Thai have consistently shown that structured, high-intensity striking training can improve aerobic capacity and components of physical fitness.^(10,12) Similarly, a systematic review of high-intensity interval

training in combat sports found significant increases in VO_2 max (mean improvements of about $2\text{--}3 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) in both striking and grappling athletes, indicating that intermittent, fight-specific conditioning reliably enhances cardiorespiratory fitness. In addition, a systematic review of upper-body exercise training in healthy individuals showed that 6–11 weeks of targeted upper-body endurance training produced average VO_2 peak-arm gains of roughly 15–17%, demonstrating that localized training can substantially improve upper-body aerobic fitness and endurance performance.^(13,14)

Overall, the existing literature provides fairly consistent evidence that Muay Thai or similar striking-based programs, when delivered at sufficient intensity, improve VO_2 max and general physical fitness, but several aspects remain only partially explored. In spite clearly showing that Muay Thai improved fitness in untrained women, regardless of the number of sessions per week, yet Rapkiewicz et al.⁽¹¹⁾ did not deeply analyze dose–response differences in VO_2 max or specific muscular endurance outcomes between frequencies, leaving some uncertainty about the optimal weekly volume for non-athletes. Vasconcelos et al.⁽¹³⁾ conducted a systematic review and meta-analysis showing that high-intensity interval training (HIIT) in combat sports consistently produces moderate-to-large improvements in VO_2 max across disciplines. However, substantial heterogeneity related to training frequency, session structure, intervention duration, and participant characteristics indicates that the optimal frequency–response relationship remains unclear. Marterer et al.⁽¹⁴⁾ systematically reviewed the effects of upper-body exercise training in healthy individuals and found that such training can significantly improve aerobic fitness, including VO_2 max, particularly when performed at moderate to high intensities. The magnitude of improvement varied across studies depending on training modality, intensity, and duration, indicating that upper-body–dominant exercise can meaningfully contribute to aerobic adaptations.

A short review presented the great difficulty of measuring training intensity with combat sports modalities due mainly to physical confrontation, intervals and plyometrics.⁽¹⁵⁾ As a result, many existing studies lack precise control and reporting of both internal and external training loads. In addition, prior research is often limited by methodological weaknesses, including the absence of randomized designs, reliance on simple

control groups, and insufficient description of training protocols. To address these gaps, the present study employed a randomized longitudinal design to compare different training frequencies of a combat sport modality (Muay Thai), with standardized intervention protocols and objective performance outcomes, thereby providing a clearer evaluation of training dose–response effects. This study specifically tested how different Muay Thai training frequencies affect VO_2 max and segment-specific muscular endurance of the upper, middle, and lower body in non-athlete adults using a pretest–posttest design, whereas earlier Muay Thai and combat-sport research either focused on general fitness in untrained women without detailed regional endurance outcomes or dose–response analysis, or relied on athlete samples and non–Muay-Thai, ergometer-based protocols rather than real-world Muay Thai sessions with systematically varied frequency. The objective of this research was to evaluate the effect of Muay Thai training frequency on VO_2 max and the muscular endurance of the upper, middle, and lower body in non-athlete adults.

METHODS

Research design

This study used an experimental study using two-group pretest-posttest design, focusing on the difference between two experimental groups, and also measuring the difference before and after the intervention. The intervention was carried out for 8 weeks (2 months) between July and August 2025 at Revolt Space Gym, located in Bandung City, West Java.

Study subjects

The inclusion criteria for this study were individuals aged 20–25 years, male or female, who were classified as non-athletes and had no prior experience in Muay Thai training or other combat sports. Participants were required to be willing to provide written informed consent and to commit to completing the entire intervention period and all study assessments. In addition, eligible participants were required to have an estimated maximum heart rate calculated as 220 minus age (in beats per minute), with the corresponding target training heart rate range of 70–85% falling within the expected physiological range without abnormal deviation during screening. The exclusion criteria included a

history of cardiovascular disease, diabetes, chronic respiratory disorders, or musculoskeletal problems. Participants were also excluded if they were following a specific diet, regularly consuming supplements or whey protein, actively smoking, or consuming alcohol. Individuals who regularly used steroids or corticosteroids were excluded. Female participants were excluded if they were using hormonal contraception, pregnant, or breastfeeding. In addition, individuals who worked night shifts were not eligible to participate in the study.

This study determined the sample size using G*Power for detecting between-group differences in post-intervention change scores (e.g. mean differences in VO₂ max and muscular endurance between two independent groups) with a two-tailed α of 0.05, power ($1-\beta$) of 0.80 and an effect size ($d=0.8$), resulting in a minimum of about 20 participants per group and a final target of 40 participants, consistent with general recommendations for experimental studies.⁽¹⁶⁻¹⁸⁾

In this study, simple computer-generated randomization was applied using the GraphPad randomizer tool, which allocated 40 participants into two equal experimental groups ($n=20$ per group) without stratification; the randomization list was generated by a researcher who was not involved in outcome assessment to reduce allocation bias.

The intervention consisted of Muay Thai training for both groups, with the only difference being the training frequency. Group 1 or MT2X ($n=20$) trained Muay Thai 2 times per week for 120 minutes per session. Group MT2X trained on Mondays and Wednesdays between 16.00 -18.00. For group 2 or MT4X ($n=20$), the Muay Thai training was 4 times per week for 120 minutes per session. Group MT4X trained on Tuesdays, Thursdays, Saturdays, and Sundays between 16.00 -18.00.

Intervention

The intervention for this study was Muay Thai training. All research participants engaged in Muay Thai training for two months, with each session lasting a total of 120 minutes. The session began with a 5-minute stretching routine to prepare the muscles and enhance flexibility. This was followed by a 10-minute warm-up (including 2 minutes of resting time) consisting of jogging and jumping jacks to raise the heart rate and ready the body for more intense activity. During the conditioning phase, the training was divided into

two parts: a 10-minute strength workout (including a 2-minute resting time) using weights such as dumbbells and kettlebells, and a 15-minute endurance workout (including a 6-minute resting time) comprising push-ups, sit-ups, squats, burpees, and floor climbing to build overall stamina. Then the session focused on 30 minutes (including a 12-minute resting time) of technique practice, which involved training various punches and kicks such as jab, cross, hook, uppercut, knee strike, elbow strike, and kick, along with shadow boxing and the use of protective gear such as hand wraps and gloves. The core of the program was a 40-minute (including a 20-minute resting time) cardiovascular training segment using a high-intensity interval training (HIIT) method in the form of a padding session, aimed at improving cardiovascular fitness and explosive power. The session concluded with a 10-minute cool-down through stretching to help muscles recover and reduce the risk of injury after intense exercise.

The duration of a 120-minute Muay Thai training session appears to be sufficiently long. However, such duration is well supported by previous studies and common Muay Thai training protocols. Effective Muay Thai training often includes multiple components such as warm-up, technique practice, bag work, sparring rounds, and cool-down, which collectively require around 90 to 120 minutes per session.⁽⁸⁾ Moreover, intermittent rounds of high-intensity work followed by rest periods, typical of Muay Thai, demand extended sessions to elicit physiological adaptations that improve muscular endurance, cardiovascular fitness, and skill acquisition.⁽¹¹⁾ Research also shows that 6-8 hours of weekly Muay Thai training, translating roughly to 2-hour sessions three times a week, balances training volume and recovery, fostering fitness improvements without excessive fatigue.⁽¹⁹⁾ Therefore, a 120-minute session aligns with established protocols in Muay Thai training research and practice, making it a feasible and justified training duration for both athletes and non-athletes aiming to improve physical fitness and combat skills.

Measurements

Data collection began with measuring VO₂ max and muscle endurance for each participant before the intervention started, referred to as the pre-test (base-line). After the intervention period, measurements were taken again for each

participant, known as the post-test. These data were then processed and analyzed to evaluate the effectiveness of the Muay Thai training intervention.

VO₂ max measurement

This study used the Harvard Step Test (HST) to measure VO₂ max, which assesses aerobic capacity or the maximum amount of oxygen that the body can use during exercise. The test involves stepping up and down a platform at a set pace for 5 minutes, followed by measuring the heart rate during recovery to estimate VO₂ max. The formula used is the Harvard Step Test formula⁽²⁰⁾ to calculate the Fitness Index:

$$\text{Fitness Index} = \frac{\text{Test duration in seconds} \times 100}{2 \times (\text{HR1} + \text{HR2} + \text{HR3})}$$

HR1, HR2, and HR3 represent heartbeats counted during specific intervals after the test: HR1 from 1 to 1.5 minutes, HR2 from 2 to 2.5 minutes, and HR3 from 3 to 3.5 minutes post-test. The test duration is the total time in seconds until the participant finishes or stops the test.

The Harvard Step Test is a widely used submaximal exercise protocol designed to estimate maximal aerobic capacity (VO₂ max) through a simple stepping exercise. Studies have demonstrated the validity and reliability of this test for predicting VO₂ max, especially in healthy young adults. Research by Ho et al.⁽²⁰⁾ used a 3-minute step test protocol, conceptually related to the Harvard Step Test, and showed that heart-rate responses during and after the step test can be used together with age, sex, and body composition to build accurate VO₂ max prediction models in healthy adults. Among six models, those that combined step-test heart-rate indices with percent body fat (especially Model PBF3) provided the best performance, explaining about 69% of VO₂ max variance with relatively low prediction error and good validity and reliability on cross-validation and Bland–Altman analysis. Overall, Ho et al.⁽²⁰⁾ concluded that their step-test-based VO₂ max equations offer a simple, low-cost, and practical tool for cardiorespiratory fitness evaluation that can be applied in primary healthcare, remote health monitoring, and cardiac rehabilitation, particularly when maximal exercise testing is not feasible. Research by Matsuo et al.⁽²¹⁾ further enhanced VO₂ max estimation by

combining heart rate responses during stepping and recovery in regression models, improving prediction accuracy. This approach recognizes that fitter individuals show lower heart rate increases during exercise and more rapid recovery post-exercise. The Harvard Step Test's ease of administration, minimal equipment requirements, and validated predictive algorithms make it a reliable method for assessing cardiorespiratory fitness, particularly in settings where maximal exercise testing is impractical or not feasible. The unit mL/kg/min for VO₂ max denotes milliliters of oxygen consumed per kilogram of body weight per minute, serving as a relative measure of maximal oxygen uptake that enables standardized comparisons across individuals of varying body sizes during incremental exercise tests such as treadmill or cycle ergometry.⁽⁶⁾

Muscle endurance measurement

In this study, the instruments used were the 1-minute push-up test for measuring upper body muscle endurance. The 1-minute sit-up test was used for measuring abdominal muscle endurance. Lastly, the squat endurance test was used for measuring lower body muscle endurance. The purpose of afore-mentioned tests was to assess the endurance of muscles in these body regions and provide an overview of the participants' physical fitness levels. The measurement standards were adapted from international and national guidelines to ensure accurate interpretation of the test results.

Muscle endurance assessment through field tests such as the 1-minute push-up, sit-up, and squat endurance tests has been widely validated as practical and reliable methods for evaluating muscular endurance in diverse populations. The 1-minute push-up test, involving continuous push-ups performed within one minute, assesses upper body muscle endurance and has demonstrated high interrater reliability and validity in reflecting muscular fitness. Similarly, the 1-minute sit-up test measures abdominal muscle endurance and shows good correlation with core strength and endurance, established through standardized protocols involving proper exercise form and timing. The 1-minute squat endurance test, targeting lower body muscular endurance, is conducted by executing as many controlled squats as possible within sixty seconds, showing consistent reproducibility and construct validity in different age groups. The unit of measurement for the 1-minute squat endurance test is the number of repetitions (repetitions/min), defined as the total

number of correctly performed squats completed within 60 seconds. These tests are efficient, require minimal equipment, and are suitable for both research and practical fitness assessment due to their validated accuracy and reliability.^(22,23)

Statistical analysis

Statistical analyses were performed using SPSS version 27. Data normality was assessed using the Shapiro–Wilk test. Baseline characteristics were compared between groups using independent t-tests and were presented as mean \pm standard deviation (SD). The primary analysis focused on between-group differences in post-intervention outcomes. Analysis of covariance (ANCOVA) was used to compare post-intervention VO₂ max and upper, middle, and lower body muscle endurance between groups, with baseline values of each outcome included as covariates. Adjusted means were reported with standard errors (SE). A two-tailed p-value <0.05 was considered statistically significant.

Ethical clearance

All procedures for this study involving humans were approved by the Research Ethics Committee, Universitas Kristen, Bandung, under number 163/KEP/VII/2025.

RESULTS

Respondent characteristics

A total of 60 individuals were assessed for eligibility, of whom 20 were excluded due to not meeting the inclusion criteria (n=15) or declining to participate (n=5). The remaining 40 participants were randomly allocated into two intervention groups, with 20 participants assigned to each group. All participants received the allocated intervention, completed the 8-week follow-up period, and were included in the final analysis. No participants were lost to follow-up or excluded from the analysis (Figure 1).

At baseline, age, sex distribution, BMI, and upper body muscle endurance were comparable between the two groups ($p>0.05$). In contrast, baseline VO₂ max and middle abdominal and lower body muscle endurance were higher in the MT4X group compared with the MT2X group

($p<0.001$; Table 1). These baseline differences were accounted for in the primary analysis using ANCOVA, with baseline values included as covariates.

Results from the VO₂max assessment

Post-intervention VO₂ max outcomes are presented in Table 2. Because baseline VO₂ max differed between groups, between-group comparisons were performed using analysis of covariance (ANCOVA) with baseline VO₂ max included as a covariate. After adjustment, participants in the MT4X group demonstrated a significantly higher post-intervention VO₂ max compared with those in the MT2X group (adjusted group effect, $p<0.001$). This finding indicates that Muay Thai training performed four times per week resulted in greater improvements in aerobic capacity than training twice per week, independent of baseline differences.

Results from the upper muscle endurance assessment

Post-intervention push-up outcomes are presented in Table 2. Given baseline differences, between-group comparisons were performed using analysis of covariance (ANCOVA) with baseline push-up scores included as covariates. After adjustment, the MT4X group demonstrated significantly higher post-intervention push-up performance compared with the MT2X group (adjusted group effect, $p<0.001$), indicating greater upper body muscle endurance associated with the higher training frequency.

Results from the abdominal muscle endurance assessment

Post-intervention sit-up outcomes are presented in Table 2. Because baseline sit-up performance differed between groups, between-group comparisons were conducted using analysis of covariance (ANCOVA) with baseline sit-up values included as covariates. After adjustment, the MT4X group demonstrated significantly higher post-intervention sit-up performance compared with the MT2X group (adjusted group effect, $p<0.001$), indicating greater abdominal muscle endurance associated with the higher training frequency.

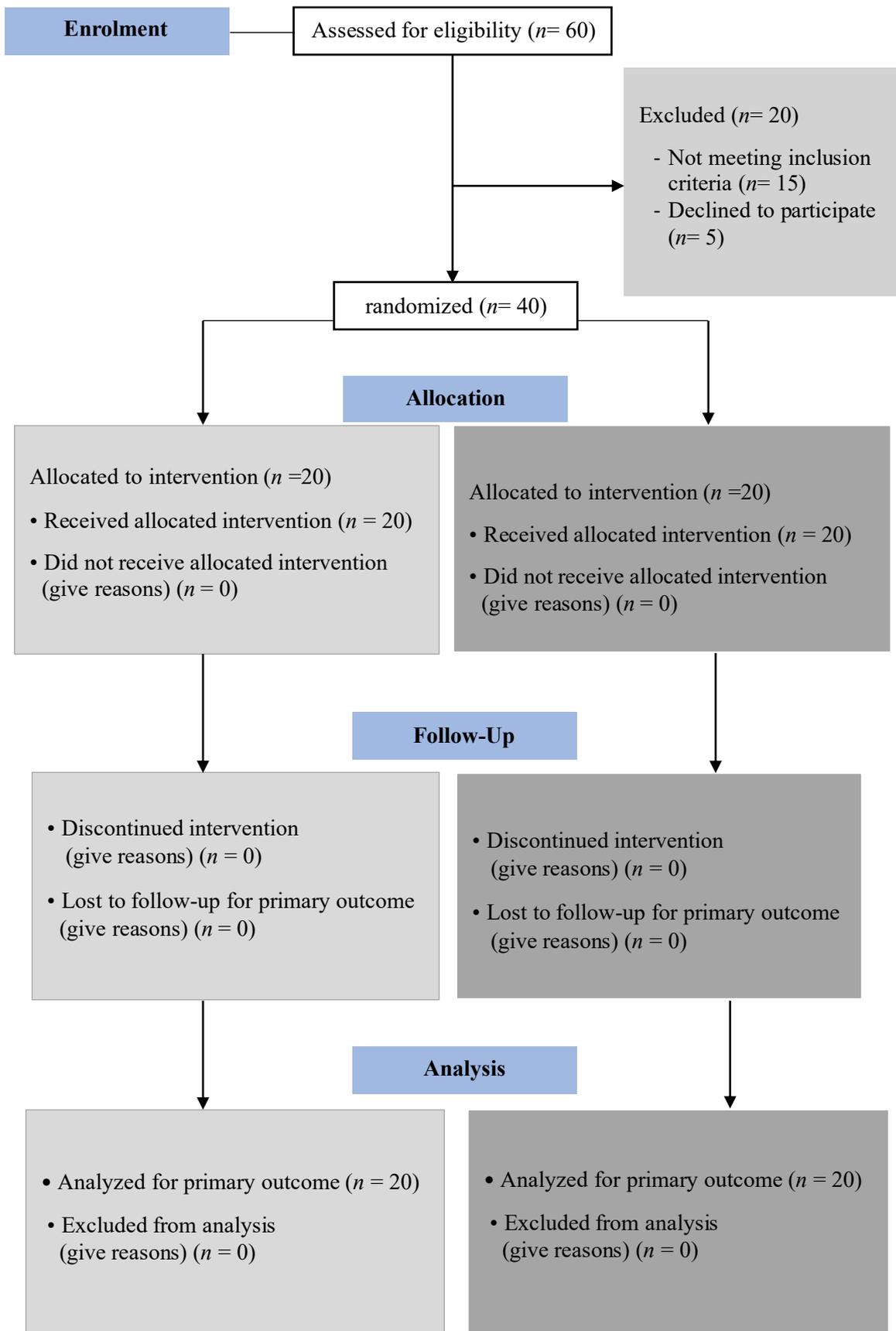


Figure 1. Flow chart of the participants

Table 1. Baseline demographics and VO₂ max, upper muscle and abdominal muscle endurance description by treatment groups

Variables	Treatment groups		p value
	MT2X (n=20)	MT4X (n=20)	
Age (years)	22.90 ± 1.61	22.85 ± 2.15	0.934
Gender			
Male	7 (35.0)	11(55.0)	-
Female	13 (65.0)	9 (45.0)	-
VO ₂ max	42.55 ± 3.25	50.80 ± 5.39	<0.001**
Upper Muscle Endurance	19.55 ± 2.94	20.95 ± 2.83	0.134
Abdominal Muscle Endurance	15.10 ± 1.55	20.60 ± 1.42	<0.001**
Lower Muscle Endurance	36.70 ± 1.94	43.95 ± 2.11	<0.001**

Note: Data presented as mean ± SD, except for gender in n (%); MT2X= Group 1 (Muay Thai frequency 2 times per week); MT4X= Group 2 (Muay Thai frequency 4 times per week); n= Sample size; **=very significant, p<0.001; p>0.005=not statistically significant

Results from the lower muscle endurance assessment

Post-intervention squat outcomes are presented in Table 2. Given baseline differences in squat performance between groups, between-group comparisons were performed using analysis of covariance (ANCOVA) with baseline squat values included as covariates. After adjustment, the MT4X group demonstrated significantly higher post-intervention squat endurance compared with the MT2X group (p=0.018), indicating greater lower body muscular endurance associated with the higher training frequency.

DISCUSSION

The study results indicate that the frequency of Muay Thai training significantly influences VO₂ max levels in non-athlete adults. After adjustment for baseline differences using ANCOVA, higher training frequency was associated with significantly greater post-

intervention VO₂ max compared with lower training frequency, indicating a frequency-dependent aerobic adaptation. This finding aligns with existing literature demonstrating that increasing the frequency and volume of aerobic exercise enhances aerobic capacity. A meta-analysis reported that exercise performed at a variety of intensities can elicit relatively similar improvements in VO₂ max, whereas total training volume and the frequency of training sessions remain critical factors when designing programs to enhance aerobic capacity.⁽²⁴⁾

The observed improvement in aerobic capacity following Muay Thai training further supports the effectiveness of this exercise modality in improving cardiovascular function and aerobic endurance. Rather than reflecting within-group changes, the present findings emphasize between-group differences after baseline adjustment, indicating that a higher weekly training frequency confers superior aerobic benefits.

Table 2. Comparison of VO₂ max and muscle endurance between groups after 8 weeks of intervention, through analysis of covariance

Outcome	MTX2 adjusted mean ± SE	MTX4 adjusted mean ± SE	Adjusted mean difference (95% CI)	p value
VO ₂ max (mL·kg ⁻¹ ·min ⁻¹)	49.28 ± 0.90	52.73 ± 0.88	+3.45 (≈ 2.1 to 4.8)	<0.001**
Upper muscle endurance (push-ups)	24.97 ± 0.72	30.68 ± 0.70	+5.71 (≈ 3.9 to 7.5)	<0.001**
Abdominal muscle endurance (sit-ups)	24.68 ± 0.55	26.67 ± 0.54	+1.99 (≈ 1.0 to 3.0)	<0.001**
Lower muscle endurance (squats)	54.56 ± 0.80	53.24 ± 0.79	+1.31 (≈ 0.2 to 2.4)	0.018*

Note : MT2X= Group 1 (Muay Thai Frequency 2 times per week); MT4X= Group 2 (Muay Thai Frequency 4 times per week); **=very significant, p<0.01; *=significant, p<0.05

Additionally, research by Saravia et al.⁽⁸⁾ found that both functional training and Muay Thai significantly enhance aerobic capacity and cardiovascular parameters in adults, reinforcing the conclusion that higher training frequency contributes to VO_2 max improvements. A study by Gao et al.⁽²⁵⁾ demonstrated that engaging in aerobic exercise at least three times per week for 12 weeks results in significant VO_2 max gains compared to lower frequencies. This benefit arises because more frequent exercise stimuli promote cardiovascular and metabolic adaptations, including increased cardiac efficiency and muscle capillarization.

In high-intensity interval training (HIIT), training frequency also plays a crucial role in achieving maximum improvements in VO_2 max and cardiorespiratory health. Research indicates that a HIIT program performed at least three times per week over a period of 6 to 12 weeks effectively enhances aerobic capacity and reduces the risk of cardiovascular diseases.⁽²⁶⁾ Muay Thai training can be conceptualized as a sport-specific HIIT modality, characterized by repeated bouts of intense physical exertion interspersed with short recovery periods, which place substantial demands on the cardiovascular system.

From a physiological standpoint, the cardiovascular adaptations induced by Muay Thai-based HIIT are multifaceted, notably including improvements in blood pressure regulation and heart rate dynamics. A recent randomized clinical trial reported significant reductions in diastolic blood pressure after 12 weeks of Muay Thai training, alongside a lowered double product, an index indicative of myocardial oxygen demand and cardiac workload, compared to functional training alone. These adaptations suggest enhanced cardiac efficiency and reduced cardiac stress following HIIT Muay Thai intervention.⁽⁸⁾ These adaptations support the greater aerobic capacity observed in participants exposed to higher training frequencies, suggesting improved cardiac efficiency and reduced cardiovascular strain.

Adaptations also extend to autonomic regulation of the heart, particularly reflected in improved cardiac autonomic modulation. The practice of Muay Thai through HIIT modulates autonomic balance by increasing parasympathetic tone and decreasing sympathetic drive, which is evidenced by lower resting heart rates and heart

rate variability improvements in populations undergoing Muay Thai training. This autonomic shift favors cardiovascular health by enhancing vagal control over the heart, which can lead to better recovery dynamics post-exercise and a diminished risk of arrhythmias associated with high sympathetic activity.^(8,27)

The Muay Thai HIIT protocol's intermittent nature and high intensity stimulate powerful hemodynamic responses, including acute elevations in heart rate, stroke volume, and cardiac output during activity. These responses evoke structural and functional cardiac adaptations over time, such as increased left ventricular volume and enhanced stroke volume at rest and during submaximal efforts. The repetitive stress-recovery cycles inherent in HIIT foster myocardial remodeling that supports sustained improvements in cardiovascular performance and endurance capacity. Moreover, high-intensity training has been shown to improve endothelial function, a crucial factor for vascular health, by increasing nitric oxide-mediated vasodilation and reducing arterial stiffness, further contributing to efficient cardiovascular regulation in response to exercise.^(8,28)

Finally, the cardiovascular benefits seen with Muay Thai-based HIIT extend beyond central cardiac mechanisms to include peripheral adaptations such as improved vascular endothelial function and arterial compliance. The intermittent bouts of high intensity promote shear stress on vascular walls, stimulating nitric oxide production which leads to vasodilation and reduced arterial stiffness. These peripheral vascular improvements contribute to overall cardiovascular health by lowering peripheral resistance and promoting efficient blood flow during rest and exercise.^(8,29)

In addition to aerobic adaptations, between-group ANCOVA results demonstrated significantly greater upper body muscle endurance in participants training four times per week compared with those training twice per week, highlighting the importance of training frequency for neuromuscular adaptation. Muay Thai incorporates repeated upper-limb striking actions that impose substantial demands on the shoulder, arm, and trunk musculature. Moderate- to high-intensity training is known to enhance muscular endurance through mechanisms such as improved motor unit recruitment, mitochondrial density, and

metabolic efficiency in skeletal muscle.^(8,30) Muscle endurance in the mid-body, particularly the abdominal muscles, is a crucial component of overall physical health and fitness. After adjusting for baseline differences, participants in the higher-frequency training group exhibited significantly superior abdominal muscle endurance, underscoring the role of consistent and frequent training stimuli in core muscle adaptation. Muay Thai involves sustained trunk stabilization, rotation, and force transmission between the upper and lower extremities, which likely contributes to enhanced abdominal muscle endurance. Previous studies have similarly demonstrated that functional and high-intensity training modalities improve core muscle capacity and metabolic efficiency.^(31,32)

Lower body muscle endurance also showed significantly greater post-intervention performance in the higher-frequency training group after baseline adjustment, indicating enhanced lower-limb endurance capacity. The squat endurance test effectively reflects functional performance of the lower extremities, which are heavily engaged during Muay Thai through kicking, footwork, and defensive maneuvers.⁽³³⁾ Moderate to high-intensity exercises such as Muay Thai are known to stimulate neuromuscular adaptations and hypertrophy in both type I and type II muscle fibres, enhancing muscle endurance and strength.⁽³⁴⁾ Optimal lower limb muscle performance is closely linked to better balance, reduced fall risk, and overall functional capacity in adults, particularly as motor function declines with age.⁽³⁵⁾

Collectively, the present findings demonstrate that higher-frequency Muay Thai training yields superior improvements in aerobic capacity and muscular endurance compared with lower training frequency, with important clinical implications. Improved VO₂ max and muscular endurance are key protective factors against lifestyle-related diseases such as obesity, hypertension, and metabolic syndrome. Structured Muay Thai training may therefore serve as an effective intervention to enhance cardiometabolic health and functional capacity in non-athlete adults.

When compared with studies conducted in other non-athlete populations, such as university students or young adults, the results are consistent. Research on recreational exercise interventions in these groups has similarly reported increases in

VO₂ max, cardiovascular fitness, and muscular endurance when training was performed at least two to three times per week. For example, a systematic review by Yin et al.⁽³⁶⁾ confirmed that HIIT significantly improves VO₂ max and muscular strength in university students. Furthermore, a systematic review by Muñoz-Vásquez et al.⁽³⁷⁾ highlighted that Olympic combat sports interventions in non-athlete populations also improved cardiorespiratory fitness, reinforcing the applicability of such training methods beyond athletes. This suggests that the benefits observed in the current study are not exclusive to trained athletes but are also applicable to general populations with varying fitness levels.

From a practical standpoint, these findings support the recommendation that young adults, particularly university students and office workers with predominantly sedentary routines, engage in Muay Thai training two to four times per week. Such a frequency appears optimal to stimulate cardiovascular and muscular adaptations while remaining feasible within busy schedules. In addition, the diverse movement patterns in Muay Thai—combining aerobic, anaerobic, strength, and coordination components—make it an efficient and enjoyable alternative to conventional exercise routines. Therefore, Muay Thai can be considered a practical and accessible strategy to promote physical health, combat sedentary behaviours, and improve overall fitness in both athletic and non-athletic populations.

Several limitations should be acknowledged. The relatively small sample size limits generalizability, and only two training frequencies were evaluated. Training intensity was not directly quantified using objective external load measures. Future studies should include larger and more diverse populations, examine a wider range of training frequencies and intensities, and incorporate objective measures of training load. For future trials, block randomization with block sizes of four or six may be considered to further minimize baseline imbalance.

CONCLUSIONS

This study demonstrates that Muay Thai training frequency significantly affects aerobic capacity and muscular endurance in non-athlete adults. After adjustment for baseline differences, training four times per week resulted in greater improvements in VO₂ max and upper, abdominal, and lower body muscle endurance compared with

twice-weekly training. These findings suggest that higher-frequency Muay Thai training provides superior physiological benefits and may serve as an effective exercise strategy to improve physical fitness and counteract sedentary lifestyles.

Conflict of interest

Competing interests: No relevant disclosures.

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Author Contributions

AHHPP and JWG initiated the research idea and managed the pretest and posttest. YL and OAA managed data collection. AHHPP, JWG, OAA, and YL managed data analysis and interpretation. JWG, OAA, and YL oversaw and reviewed the manuscript, and drafted the final version of the manuscript. All authors read and approved the final version of the review.

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Data Availability Statement

Original data used in this study may be requested directly from the corresponding author.

Declaration of AI Usage in Scientific Writing

The authors used Grammarly to improve English writing, ChatGPT and Perplexity to improve the quality of the writing, and then all authors reviewed and edited the content before submitting the manuscript.

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